ASSESSING BIOPHYSICAL CHARACTERISTICS OF GRASSLAND FROM SPECTRAL MEASUREMENTS

by

Russell L. Weiser

B.S., Oregon State University, 1983

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Agronomy

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1985

Approved by:

Edward T. Kanemasu

Major Professor

TABLE OF CONTENTS

ABSTRACT

Remote sensing offers a potential alternative to tedious hand sampling as a means of monitoring vegetation condition and estimating productivity over large areas of grasslands.

Spectral reflectance measurements were made on a tallgrass prairie (Konza Prairie) near Manhattan, Kansas during 1983 and 1984 with two multiband radiometers (Barnes MMR and Exotech model 100-A). Measurements were made on a weekly basis depending on the weather. Two treatments were examined: one prairie treatment was burned in the spring and the other was left unburned with the previous year's senescent grasses covering the soil. Green leaf area index and dry matter accumulations (green above ground phytomass) were measured on the area monitored by the radiometer. Three indices: near-infrared to red ratio (NIR/RED), greenness (GN), and normalized difference (ND) were computed from spectral reflectance data.

Reflectance index values calculated from 1983 data were used to develop regression models with LAI and green phytomass. The NIR/RED gave the best results for both parameters when these models were tested on 1984 data. Measured and estimated values were found to be signifigantly different for LAI, but not for green phytomass.

Leaf area index and green phytomass were also estimated from models utilizing canopy interception of photosynthetically active radiation as estimated from 1984 NIR/RED. When tested on 1983 data estimated and measured values for both LAI and green phytomass were not signifigantly different. Since this approach is based on physical attributes of canopy structure (for LAI) and energy absorption (for phytomass), its application should extend to different sites and years.

Table 1. Regression statistics for LAI vs. the different reflectance indices for the burned and unburned treatments of 1983 (B83 and U83) and 1984 (B84 and U84) for both Barnes and Exotech radiometers.

Table 2. Comparison of regression models of LAI versus each reflectance index for different treatment-year combinations.

Table 3. A) Equations developed for estimation of LAI from 1983 reflectance data. B) Statistics from regression of measured vs. estimated LAI for 1984 data.

Table 4. Regression statistics for PAR interception estimated from GN, ND, and NIR/RED from Barnes and Exotech data collected in 1984 and 1985.

Table 5. Regression statistics for measured versus estimated (indirectly) LAI for models where GN, ND, and NIR/RED from Barnes and Exotech data.

Table 6. Linear regression statistics for estimation of green phytomass from greenness, normalized difference and NIR/RED for the burned and unburned treatments for 1983 (B83 and U83) and 1984 (B84 and U84).

Table 7. Comparison of regression models of green phytomass versus each reflectance index for the different treatment-year combinations.

Table 8. Regression statistics for green phytomass (dependent variable) versus each reflectance index for all 1983 data.

Table 9. Regression statistics for green phytomass estimated by each reflectance index (dependent variable) versus measured green phytomass for 1984 data.

INTRODUCTION

Remote sensing offers a potential in agriculture for estimation of crop growth, condition, and yield. Traditional field methods of hand sampling of vegetation over a given ground area is time consuming, expensive, and destructive. In the past spectral reflectance of crop canopies in the visible and infrared wavebands has been used to calculate reflectance indices such as normalized difference, greenness, and a ratio of near infrared to red reflectance. These were related directly to crop parameters such as leaf area index (LAI) and dry weight of plant material produced. Although strong relationships were commonly found they were often inconsistent over different years and locations.

The objective of this study was to estimate LAI and dry phytomass of a native tallgrass prairie from spectral data. Burned and unburned treatments were used to obtain a range of LAI and phytomass. Multispectral reflectance data were collected over a period of two growing seasons (1983 and 1984).

I. LITERATURE REVIEW

Using remote sensing as a tool in agriculture to estimate the productivity or condition of a plant canopy depends on our ability to understand the spectral characteristics of the components of the canopy and the soil background. The interaction between incoming radiant energy and the leaves determines the quantity of incoming radiation that is absorbed, reflected, and transmitted by the canopy; and hence the potential for processes such as photosynthesis, evapotranspiration, and growth.

A. LEAF REFLECTANCE

Current hypotheses of leaf reflectance arose from the Willstätter and Stoll theory (1918). Their theory is based on the assumption that reflectance of visible radiation occurs within a leaf when light passing through an area of low refractive index strikes an area of higher refractive index at an angle of incidence greater than the critical angle for reflection. Willstätter and Stoll thought this was most likely to occur in the spongy mesophyll of leaves where many cell-air interfaces occur. Higher reflectance was observed from the abaxial side where spongy mesophyll occurred, supporting this hypothesis.

Mestre (1935) asserted that reflectance from the leaf surface could occur as well by specular or diffuse reflectance depending on the glossiness of the cuticle or density of pubescence on the leaf surface. Upon entry into the leaf the path length of light was increased because it could not exit

unless it struck the surface at an incidence angle less than the critical angle. The longer path length would allow more opportunities for visible light to be absorbed by photopigments (chlorophyll and carotenoids).

Dinger (1941) found near infrared radiation was not absorbed by chlorophyll. Consequently, intact leaves had high reflectance and transmittance in that spectral region. Sinclair et al. (1973) proposed that the microfibrils composing cell walls act as diffusive reflecting surfaces that obey Lambert's cosine law. Gausman (1977) using infrared photography of leaf components showed that stomata, nuclei, cell walls, crystals, and cytoplasm also contributed to the reflectance of light in the near infrared (0.7-1.1 um) region.

The characteristic spectral reflectance, transmittance, and absorptance of light by a green leaf (Fig. 1) is determined by the pigments, cell structure, cell components, and cell numbers. The high absorptance in the visible region is due to photopigments. The reflectance and transmittance are greater in the middle infrared region due to diffraction by cell components. Absorptance in the middle infrared region is due to water. During leaf senescence the infrared reflectance remains constant as long as the cell structure is intact, but red and blue reflectance increases as the sensitive photopigments breakdown.

B. CANOPY REFLECTANCE

The reflectance of a plant canopy is similar to that of individual leaves, but modified by background reflectivity, canopy structure, shadows, and view angle. Bowers and Hanks (1965) described the reflectance properties of soils in the

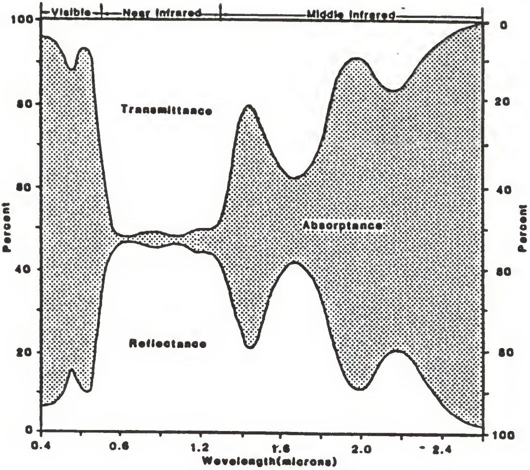


Figure 1. Reflectance, transmittance, and absorptance of radiation by a typical healthy green leaf; adapted from Knipling (1970).

visible and infrared region and said they were affected by moisture content, particle size, and organic matter. By increasing moisture content, soil reflectance decreased and absorptance increased. Removal of organic matter increased reflectance, and reflectance was inversely proportional to particle size. Kanemasu (1974) also found soil reflectance was sensitive to soil moisture, especially in near infrared wavelengths. Huete et al. (1984) studied the reflectance properties of 20 different soil types in relation to plant canopy development and found the best contrast between spectral characteristics of soil background and vegetation is provided by considering individual soils as compared with the combination of all soils. If the reflectance of the soil and vegetation is similar at a particular waveband, the relationship between reflectance and area covered by vegetation will be weak. It follows (Fig. 2) that red and near infrared are the best wavebands for estimation of vegetation amount because reflectance of living vegetation differs most from soil reflectance in these regions. Tucker and Miller (1977) found experimentally that wavelengths of 0.68 and 0.75 um showed the greatest soil-dry green phytomass reflectance contrasts for blue grama grass (Bouteloua gracilis (H.B.K.) Lag.)

Besides soil and leaf reflectance, leaf area and orientation, reflectance of plant components other than leaves, solar zenith angle, look angle, and solar azimuth angle affect the canopy reflectance (Colwell, 1974).

The orientation of leaves in space determines the leaf area projected to a sensor. Leaf orientation is relatively constant

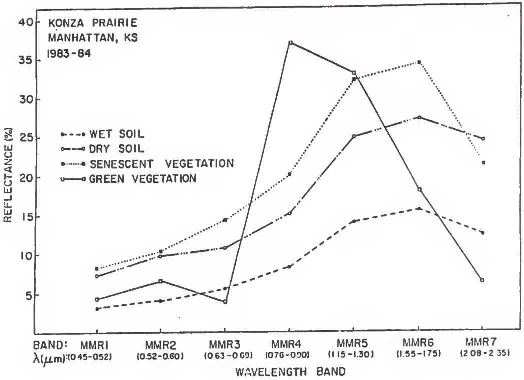


Figure 2. Reflectance of wet and dry bare soil, and green and senescent prairie vegetation, as measured by Barnes MMR; from Asrar et al. (1985d).

for a given species but may fluctuate seasonally and diurnally as a result of disease, stress, or wind movement (Knipling, 1970). The canopy reflectance may increase in the visible region if chlorophyll pigments are destroyed. The canopy reflectance is altered as a result of stress by a change in the leaf area projected to the sensor. This may occur by loss of leaves, change in orientation, or reduced growth, and will affect the near infrared region more than visible in full canopies because of the greater number or leaf layers required for maximum near infrared reflectance. Plant components other than leaves such as stems, branches, or inflorescences may alter canopy reflectance. Solar zenith angle and azimuth angle affect reflectance by determining the area and darkness of shadows (Curran, 1980). The minimum shadow area occurs at solar noon when sun is at its highest elevation. Reflectance from areas in shadow were described by Richardson et al. (1975) as intermediate between soil and vegetation. As the sensor look angle deviates from nadir the relative proportion of soil visible decreases. Azimuth angle may affect the amount of shadow independently from the zenith angle especially before complete canopy closure in row crops when the direct solar radiation is parallel or perpendicular to row direction.

Given that soil is neither too bright or dark, leaves are mostly green, reflectance of non-leaf plant parts is minimal, and spectral readings are taken consistently near solar noon on clear days from a nadir view angle, changes in the canopy reflectance should be proportional to the vegetation density (Curran, 1980).

C. ESTIMATION OF VEGETATION DENSITY

Leaf area index (LAI), the ratio of leaf area to ground area is commonly used to measure vegetation density. Estimation of LAI by remote means has been the goal of many studies because conventional hand sampling and physical measurement of LAI is time consuming and expensive. Most of these studies have relied on reflectance in the red and infrared wavebands.

Colwell (1974) and Holben et al. (1980) found a negative correlation between LAI and red reflectance until the canopy coverage is complete, after which further increases in LAI affect red reflectance very little, while near infrared reflectance was still sensitive to increases in vegetation. Tucker (1977) studying blue grama canopies also found reflectance in regions of strong pigment absorption to be asymptotic at much lower vegetation levels than the near infrared region where absorption is a minimum because of the transparency of leaves at that spectral region.

If LAI could be estimated remotely and used as an input in evapotranspiration and photosynthesis models, their application could be extended for large land areas. Using LANDSAT Multispectral Scanner (MSS) data to calculate the perpendicular vegetation index (PVI), transformed vegetation index (TVI), and greenness vegetation index (GVI), Wiegand et al. (1979) concluded reflectance of wheat (<u>Triticum aestivum</u> L.) was related to and could be "calibrated" to provide LAI estimates. Pollock and Kanemasu (1979) developed an empirical model to estimate LAI of wheat in three Kansas counties from LANDSAT MSS data (R^2=0.69). This model had separate equations for LAI values below and above

0.5 units indicating the relationship changes over time in a given season. Kimes et al. (1981) showed that NIR/RED was highly correlated with the green leaf area index. Chance (1981) stated that he could calculate LAI to within 0.66 units from a prior knowledge of soil reflectance and full crop canopy reflectance using a canopy reflectance model. Kollenkark et al. (1982) found that greenness and LAI were strongly related; however, they showed an even stronger relationship between soil cover and greenness for soybeans (Glycine max L.). They also showed that greenness reached a maximum, although LAI continued to increase suggesting that at upper LAI values greenness may be saturating. Wallburg et al. (1982) found that LAI in corn (Zea mays L.) could be estimated with a near infrared to red ratio. In a two year study, Daughtry et al. (1983) found for different planting dates, populations, and soil types of corn that greenness was associated with 76% of the variation of LAI. Hatfield et al. (1985) found for various planting dates of wheat the seasonal pattern of greenness did not always follow that of LAI. The NIR/RED reflectance and LAI relationship was found to be more stable over all planting dates. Above-ground phytomass per unit area has also been used as a measure of canopy density. In some applications, especially grassland, phytomass productivity is the parameter of interest to determine stocking rates of grazing animals. Dry weight of green phytomass of wheat has been related to LAI (Aase, 1978) and may therefore be used to estimate LAI. Richardson et al. (1983) used the near infrared to red ratio (Thematic Mapper wavebands) to estimate above-ground

phytomass of Alicia grass (Cynodon spp.) rangeland at different fertility levels (R^2=0.61) in Texas. Boutton and Tieszen (1983) also used a near infrared to red ratio (0.800/0.675um) to predict green phytomass of grassland at the Masai Mara Game Reserve, Kenya (R^2=0.70); however, the relationship did not work if less than 30% of the vegetation was live. Weiser et al. (1984) found senescent vegetation of unburned tallgrass prairie in Kansas interfered with spectral estimation of LAI and phytomass.

In summary, these studies indicated that direct estimates of LAI and phytomass from spectral data were site and data set dependent, and separate relationships before and after maximum growth were often found.

D. USING PAR INTERCEPTION TO ESTIMATE CANOPY DENSITY

Interception of photosynthetically active radiation (IPAR) and spectral reflectance indices have been shown to be correlated. Fuchs et al. (1984) used IPAR data measured in three wheat cultivars at different seeding rates to indirectly determine LAI. The exponential relationship between light penetration and LAI (Monsi & Saeki, 1953) as affected by the leaf angle distribution was used to estimate LAI for various leaf angle distributions. In wheat, average leaf inclinations of 60° and 75°, and spherical distribution were acceptable for LAI estimation that was within 0.7 units of the measured LAI for a range from 1.5 to 5.0 units. Asrar et al. (1984a, 1985a) found normalized difference to correlate well with fractional PAR interception in wheat canopies up to an LAI of 6.0. Thus, this indirect technique by Fuchs et al. (1984) was used to estimate

LAI from spectrally estimated IPAR. In a similar study of a tallgrass prairie Asrar et al. (1985b) used greenness to estimate the IPAR and found the spherical leaf distribution adequately described the canopy for indirect estimation of LAI from spectrally derived IPAR.

Intercepted PAR has also been used in several studies to estimate dry phytomass accumulation. Simply stated, dry matter production is related to; 1) the quantity of incident solar radiation, 2) fraction of radiation absorbed by foliage, and 3) the efficiency of the plant stand to convert energy into dry matter, which may be affected by stage of development or exposure to stress. Hsiao and Acevedo (1974) found efficiency of conversion to be relatively insensitive to water stress. Dry matter yield depends primarily on the ability of a plant to cover the soil rapidly and intercept as much available energy as possible. Hodges and Kanemasu (1977) found the photochemical efficiency of wheat (grams phytomass produced per MJ IPAR) to change with growth stage with the most efficient conversion from emergence to jointing. Steven (1981) reported dry matter (DM) production over time (t) could be estimated from the proportion (P) of the incident solar radiation (SR) intercepted by a plant canopy according to the equation,

$$DM = \int_{t_0}^{t} E \cdot P \cdot SR \, dt$$

where E is the photochemical efficiency found to be 1-3 g/MJ for most crops. Daughtry et al. (1983) using estimates of accumulated solar radiation accounted for 65% of the variation in yield of corn. They concluded estimation of IPAR was a viable

approach for merging spectral and meteorological data in crop yield models. Tucker et al. (1983) following this approach related the cumulative integrated normalized difference to total dry matter production from satellite data over a Senegalese Sahel. Steven et al (1983) used NIR/RED (0.78-0.94um/0.60-0.66um) to estimate IPAR in sugarbeets (Beta vulgaris) and related IPAR to yield of an independently grown crop (predicted within 6% of the observed values). Wiegand and Richardson (1984), using various vegetation indices to estimate fractional IPAR in sorghum (Sorghum bicolor L. (Moench).), confirmed that cumulative interception or vegetation indices would be better than instantaneous values for estimating yield. Hatfield et al. (1984) found normalized difference was signifigantly better than greenness for estimating IPAR for five planting dates of wheat in Arizona. Separate equations were used for the growth (R^2=0.974) and senescence (R^2=0.869) of the crop. Asrar et al. (1984b) found the fractional interception of PAR radiation in wheat increased smoothly until anthesis and varied during senescence. The photochemical efficiency was highest early in the season decreasing toward maturity. Gallo et al. (1985) found in corn canopies between planting and silking that greenness, normalized difference, and NIR/RED were associated with more than 95% of the variation in IPAR. They also found cumulated IPAR was a better indicator of yield than cumulated LAI. Asrar et al. (1985c) found estimates of above-ground phytomass based on cumulated absolute daily IPAR (estimated from spectral reflectance) and a stress factor correlated strongly with observed above-ground

phytomass for a wide range of climate and plant canopy conditions in wheat. On a larger scale Tucker et al. (1985) using NOAA6 and NOAA7 advanced very high resolution data from a Senegalese Sahel over three years found a linear relationship between end of season total phytomass and normalized difference integrated over time.

II. Materials and Methods

A. Site Description

Spectral and growth analysis data were collected in 1983 and 1984 at separate locations on the Konza Prairie Research Natural Area (KPRNA) located 8 kilometers south of Manhattan, Kansas (39^{o} 9'N, 96^{o} 40'W). Soil at these two sites is a silty clay loam classified as a Udic Ustoll (Bidwell and McBee, 1973) typical of the Flint Hills uplands. The area of study is unplowed native bluestem prairie dominated by three species of grass, big bluestem (Andropogon gerardii Vitman), little bluestem (Andropogon scoparius Michx.), and indian grass (Sorghastrum nutans (L.) Nash). In addition, 36 other species of grasses, forbs, and small shrubs were identified on the 1983 site in a vegetation composition study performed on 23 August by L.C. Hulbert (personal communication). Thirty-nine species were identified in a similar study on 5 September at the 1984 site in addition to the three dominant grasses. The large number of species provide spatial diversity in canopy qualities such as leaf area, leaf size, leaf shape, and leaf color. In addition, phytomass density and spatial distribution are more variable than in monoculture crops.

Climate of the prairie uplands is humid subtropical with temperature ranges from -35 ^{o}C to 47 ^{o}C annually. Average precipitation is 800 mm per year with variable seasonal distribution resulting in many wet-dry cycles in the normal growing season of 176 days.

Two treatments were established at both the 1983 and 1984 sites on opposing sides of a fireguard. On one side the

senescent vegetation from previous years was removed by burning in the early spring (20 April 1983, 19 April 1984). The prairie on the other side of the fireguard was left unburned resulting in a senescent vegetation accumulation that covered the soil surface. These two areas will be referred to as the burned and unburned treatments, respectively.

B. **DATA ACQUISITION**

Spectral reflectance measurements were initiated the week prior to burning in 1983 and 1984 with a Barnes modular multispectral radiometer (MMR) model 12-1000 and an Exotech model 100-A radiometer. The Barnes radiometer measured reflected radiation in three discrete wavelength bands in the visible (MMR1= 0.45-0.52um, MMR2= 0.52-0.60um, and MMR3= 0.63-0.69um), two in the near infrared (MMR4= 0.76-0.90um and MMR5= 1.15-1.30um), and two in the middle infrared (MMR6= 1.55-1.75um and MMR7= 2.08-2.35um) wavelength bands. The Exotech radiometer has two wavelength bands in the visible (MSS4= 0.50-0.60um and MSS5= 0.60-0.70um) and two in the near infrared (MSS6= 0.70-0.80um and MSS7= 0.80-1.10um) regions. Both radiometers were placed on the end of a truck-mounted boom in the nadir position 8 m above the soil surface with a 15^{o} field of view. On near weekly intervals throughout the growing season at least 20 canopy reflectance measurements were taken on each treatment transect. Measurement periods were limited to near midday on clear days. Measurements were taken alternately over the two treatments and referenced to a $BaSO_4$ calibration panel every 15-20 minutes. The raw values were multiplied by calibration factors to provide a canopy

reflectance factor.

Photosynthetically active radiation (PAR) components were measured with two quantum sensors (LiCor model LI-190S) and a quantum line sensor (LiCor model LI-1915) during 1984. Measurements were initiated during mid-morning on each date by pointing all three sensors upward, leveling them, and sampling the incoming PAR 10 times for intercalibration of the sensors. To measure the PAR components the two quantum sensors were mounted on a tripod assembly and positioned above the canopy. One sensor faced upward and recorded the total (direct + diffuse) incoming PAR, the other faced downward and recorded the PAR reflected from the canopy. The line quantum sensor was placed underneath the canopy, below the last layer of green leaves, to measure PAR transmitted through the canopy. All three sensors were wired into a data acquisition system (Polycorder model 516A) for simultaneous data collection. The PAR-sensor assembly was placed at three different locations in each treatment transect. Five sets of measurements were made at each location, transferring the line quantum sensor to different spots in the vicinity of the tripod assembly. This sequence of measurements was repeated until mid-afternoon for both treatments on each day of data collection.

In 1983, four plant samples, each 0.1 m^2 of ground area, were obtained from three sampling locations established each day of reflectance measurements on each treatment transect (12 samples per treatment per date). These sites were marked to avoid resampling. In 1984, one 0.1 m^2 plant sample was obtained from nine sampling locations of each of the two treatment

transects (9 samples per treatment per date). In the laboratory, the plant samples were separated into green grass leaves, green nongrass leaves, and senescent material. Total green leaf area of both grass and nongrass species was determined using a LiCor model LI-3100 optical area meter. Wet weights were recorded and plant sample components were oven dried at 65 °C for 72 hours, then reweighed. A cubic spline procedure was applied to smooth these measured values of green leaf area and phytomass components over time.

III. RESULTS AND DISCUSSION
A. LAI estimation
1) Direct approach---regressions

In this study three spectral indices, normalized difference (ND), the near infrared to red ratio (NIR/RED), and greenness (GN), calculated from both Barnes and Exotech data were evaluated. The spectral indices were calculated as follows,

$$ND_{exotech} = (MSS7-MSS5)/(MSS7+MSS5) \quad [1]$$

$$ND_{barnes} = (MMR4-MMR3)/(MMR4+MMR3) \quad [2]$$

$$NIR/RED_{exotech} = MSS7/MSS5 \quad [3]$$

$$NIR/RED_{barnes} = MMR4/MMR3 \quad [4]$$

$$GN_{exotech} = -0.3974MSS4 -0.6849MSS5 +0.2564MSS6 +0.5543MSS7 \quad [5]$$

$$GN_{barnes} = -0.0440MMR1 -0.0240MMR2 -0.1747MMR3 +0.7916MMR4 +0.3875MMR5 -0.2387MMR6 -0.3699MMR7 \quad [6]$$

where MSS4 through MSS7 are the Exotech wavelength bands that correspond to the LANDSAT Multispectral Scanner channels, and MMR1 through MMR7 are the Barnes Modular Multispectral Radiometer wavelength bands. The greenness coefficients were derived from the 1983 data using a modified principal component analysis (PCA) as described by Miller et al. (1984). Linear regression equations were derived between the spectral indices and the smoothed measured leaf area index (LAI) data for the burned and unburned treatments in 1983 and 1984.

Ideally the slope and intercept linear regression equations should be the same for the different years and treatments. To reliably estimate grassland LAI, a regression equation should

perform well for a variety of locations, environmental conditions, times of season, species compositions, management practices, and other grassland variables. In this study a burned and an unburned treatment for 1983 (B83 and U83) and 1984 (B84 and U84) were used to provide some of these elements of diversity.

The first portion of the analysis is a comparison of the regression lines for LAI versus each reflectance index from the different treatment-year combinations. The relationship between LAI and NIR/RED for the Barnes and Exotech data is shown in Figure 3. Mean values of LAI and NIR/RED for each day of data collection during the entire season are presented for both the burned and unburned treatments for 1983 and 1984. Regression lines for the individual treatment-year combinations have been plotted with R^2 values (Table 1) ranging from 0.76 to 0.91 for Barnes and 0.80 to 0.88 for Exotech data; therefore, strong linear relationships for these individual treatment year combinations exist.

The "Extra Sum of Squares" principle (Draper and Smith, 1981) was used to test if the regression lines for the different treatment-year combinations were significantly different (Table 2). A probability level of 0.05 was arbitrarily chosen to decide whether a set of relationships were different. This probability level was used for all subsequent statistical tests. If the probability (p) value for a given comparison is greater than 0.05, it can be concluded that there is no statistically significant difference between the equations compared. The highest p-values were obtained for NIR/RED when comparing two

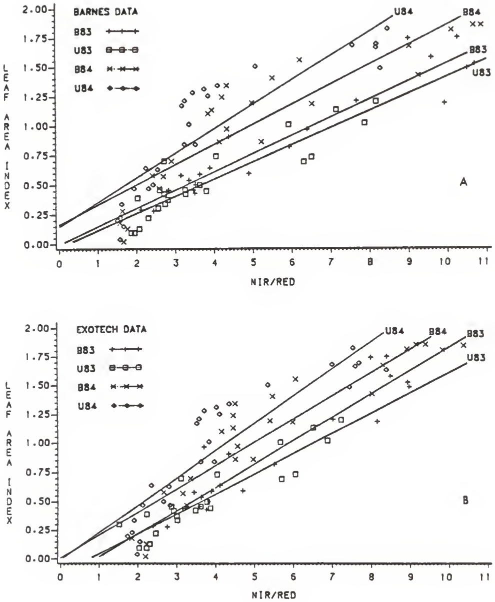


Figure 3. Relationship between leaf area index and NIR/RED for different treatment-year combinations for Barnes (A) and Exotech (B) data.

Table 1. Regression statistics for LAI vs. the different reflectance indices for the burned and unburned treatments of 1983 (B83 and U83) and 1984 (B84 and U84) for both Barnes and Exotech radiometers.

BARNES DATA

REGRESSION	TREATMENT	SLOPE	INTERCEPT	R^2	RMSE*
LAI VS. NIR/RED	B83	0.15	0.00	0.91	0.15
	U83	0.14	-0.03	0.81	0.14
	B84	0.16	0.19	0.81	0.25
	U84	0.21	0.15	0.76	0.27
LAI VS. GN	B83	4.56	-0.40	0.64	0.29
	U83	4.02	-0.46	0.77	0.16
	B84	5.55	-0.25	0.83	0.23
	U84	6.54	-0.43	0.95	0.12
LAI VS. ND	B83	3.04	-1.07	0.84	0.19
	U83	1.91	-0.47	0.82	0.14
	B84	2.76	-0.59	0.91	0.17
	U84	2.77	-0.45	0.93	0.14

EXOTECH DATA

REGRESSION	TREATMENT	SLOPE	INTERCEPT	R^2	RMSE*
LAI VS. NIR/RED	B83	0.20	-0.18	0.88	0.17
	U83	0.17	-0.13	0.83	0.13
	B84	0.20	0.01	0.84	0.22
	U84	0.24	0.00	0.80	0.25
LAI VS. GN	B83	7.35	-0.44	0.76	0.24
	U83	5.17	-0.22	0.77	0.15
	B84	9.17	-0.37	0.89	0.18
	U84	9.18	-0.21	0.94	0.14
LAI VS. ND	B83	3.75	-1.52	0.83	0.20
	U83	1.88	-0.47	0.73	0.17
	B84	3.62	-1.18	0.92	0.16
	U84	3.22	-0.77	0.92	0.15

* RMSE is the root mean squared error

Table 2. Comparison of regression models of LAI versus each reflectance index for different treatment-year combinations.

		BARNES DATA		EXOTECH DATA	
REGRESSION	COMPARISON	F_{calc}	p Value	F_{calc}	p Value
LAI VS NIR/RD	B83 vs. U83	1.07	0.3523	1.56	0.2224
	B84 vs. U84	3.35	0.0437	3.19	0.0504
	B83 vs. B84	8.10	0.0010	5.08	0.0100
	U83 vs. U84	23.77	0.0000	21.07	0.0000
	all trts.	11.45	0.0000	9.35	0.0000
	83 vs. 84	26.88	0.0000	21.28	0.0000
LAI VS. GN	B83 vs. U83	4.08	0.0245	4.16	0.0228
	B84 vs. U84	1.67	0.1989	5.05	0.0103
	B83 vs. B84	13.81	0.0000	21.26	0.0000
	U83 vs. U84	120.94	0.0000	101.66	0.0000
	all trts.	25.53	0.0000	32.32	0.0000
	83 vs. 84	63.93	0.0000	75.81	0.0000
LAI VS. ND	B83 vs. U83	6.22	0.0045	9.63	0.0004
	B84 vs. U84	5.44	0.0076	8.23	0.0009
	B83 vs. B84	17.09	0.0000	11.06	0.0001
	U83 vs. U84	71.45	0.0000	50.69	0.0000
	all trts.	26.28	0.0000	22.13	0.0000
	83 vs. 84	55.07	0.0000	35.32	0.0000

treatments for a particular year. For the 1983 Barnes data the treatments were not significantly different ($p=0.3523$), but in 1984 they were ($p=0.0437$). For the Exotech data the regression lines for the two treatments were not different for either 1983 or 1984 ($p=0.2224$ and 0.0504, respectively). When regressions for the burned or the unburned treatments were compared between 1983 and 1984 the p values were much lower ($p<0.01$) suggesting the regressions equations were different. When the data for both treatments were combined and the regressions for the 2 years were compared, they were also different ($p<0.0001$). Therefore, the data indicate year to year differences are greater than treatment differences for the NIR/RED and leaf area index relationship. The analysis of greenness and normalized difference (Figures A1&A2, Table 2) show similar results. The regression lines and statistics for the Barnes and Exotech data were slightly different, but were in good agreement and the same conclusions would be reached using data from either radiometer.

The next step in the analysis was the elucidation of a regression equation and testing its performance on an independent set of data. Since the treatment differences were small the data from the burned and unburned treatments for 1983 were combined and linear regression equations calculated by least squares estimates for measured leaf area index (dependent variable) versus each of GN, ND, and NIR/RED (independent variable), see Table 3a. The 1984 reflectance data were used to predict leaf area index from these equations. To test each equation, measured LAI from 1984 was compared with estimated LAI and a test (Appendix 1) was performed to see if the estimated

values differed from the observed values. When NIR/RED was used to estimate LAI (Fig. 4) the R^2 for the relationship was 0.76 for Barnes and 0.80 for Exotech data showing strong linear relationships; however, the p values (Table 3b) indicate that both lines are different than 1:1 lines. The seasonal trend of this model's performance is shown in Figure A3. Thus the equation developed from 1983 was not able to accurately estimate LAI from 1984 data. This confirms our earlier conclusion that the LAI vs. NIR/RED relationship was different from one year to the next. For greenness and normalized difference the relationships are also linear but differ from 1:1 lines (Figures A4&A5, Table 3b).

We conclude that the regression equations display site or data set dependency that limits their usefulness in extrapolating to different sites or for different years. Factors such as species composition, stress, canopy geometry, sun angle, zenith angle, or soil background may affect these relationships.

Differences between the 2 years can be divided into site differences and growing season differences. The 1983 site was located on a ridgetop while in 1984 the study was conducted on a lowland site. The soil depth was different between the ridgetop and lowland areas. Occasionally, limestone bedrock was exposed on the ridges. Both burned and unburned treatments were dominated by grasses, but detailed species composition studies (Tables A1&A2) indicated that nongrass types not tolerant to burning are able to invade the unburned areas displacing the grasses and thereby altering the species composition of the treatments. The

Table 3.

A) Equations developed for estimation of LAI from 1983 reflectance data.

RADIOMETER	ESTIMATION EQUATION	R^2	RMSE
Barnes	LAI= 0.154*NIR/RED - 0.04	0.89	0.14
	LAI= 4.56*GN - 0.50	0.68	0.25
	LAI= 2.52*ND - 0.77	0.82	0.19
Exotech	LAI= 0.197*NIR/RED - 0.19	0.88	0.15
	LAI= 6.60*GN - 0.37	0.76	0.22
	LAI= 2.70*ND - 0.88	0.74	0.22

B) Statistics from regression of measured vs. estimated LAI for 1984 data.

RADIOMETER	INDEX	SLOPE	INTER-CEPT	R^2	RMSE	P VALUE
Barnes	GN	0.68	-0.16	0.89	0.14	0.0000
	ND	0.85	-0.24	0.91	0.16	0.0000
	NIR/RED	0.69	-0.02	0.76	0.21	0.0000
Exotech	GN	0.67	-0.12	0.90	0.13	0.0000
	ND	0.75	-0.07	0.90	0.14	0.0000
	NIR/RED	0.77	-0.04	0.80	0.21	0.0004

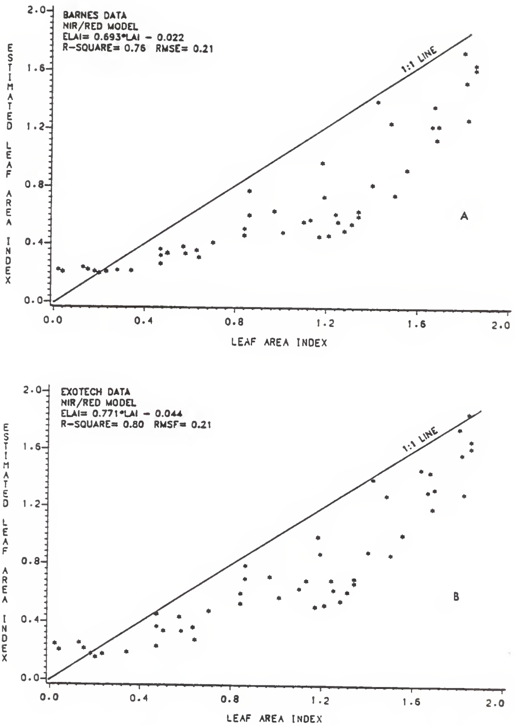


Figure 4. Leaf area index estimated from 1984 Barnes (A) and Exotech (B) data is regressed with 1984 measured LAI. Leaf area index was estimated from the NIR/RED model developed from 1983 data.

average canopy coverage for big bluestem in 1983 was 93% for the burned and 96% for the unburned areas, while in 1984 it covered 86% and 80% for the burned and unburned treatments, respectively. Some nongrass species such as western ragweed (*Ambrosia psilostachya*) and heath aster (*Aster ericoides*) had less than 10% cover in all the treatments except the unburned of 1984 where they covered 25% and 45% of the area respectively. Plant traits such as leaf angle, shape, and pigmentation are largely governed by genotype. Thus, the species differences between sites could have affected the spectral reflectance for a given LAI between the burned and unburned sites. There could also be differences in the amount of litter between the 2 years.

Growing season differences or climatic variations between years such as temperature and moisture stress may also affect the leaf angle (wilting), shape (leaf rolling), or pigmentation (chlorophyll degradation) since the development of a particular genotype is modified by its growing environment. Wilting and leaf rolling especially could reduce the projected leaf area viewed by a radiometer.

Daily and seasonal changes in solar elevation affect spectral reflectance of plant canopies (Fig. 5). However, most reflectance data in this study were collected within 1 or 2 hours of solar noon and the variability along a transect (one standard deviation) is greater than the differences in mean reflectance measurements due to solar angle. Since the vegetation on the prairie is not planted in rows, but has a non-ordered spatial arrangement, the "row effect" in spectral reflectance produced in crops by variations in solar azimuth angle is minimized.

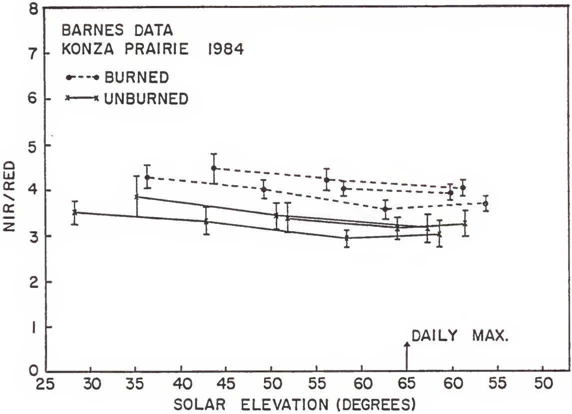


Figure 5. Reflectance ratio NIR/RED as it varies with solar elevation for days 220, 226, and 228 in 1984. Error bars are one standard deviation from the mean.

If soil background differed between years we would expect the 1983 and 1984 regression lines to converge at maximum LAI when soil background effects on the spectral reflectance are minimized. However, the regression lines diverge at high LAI (Fig. 3). This suggests other factors such as canopy geometry or a stress affect the LAI-spectral index relationship more strongly. The reason the relationship between LAI and the spectral reflectance differed between 1983 and 1984 cannot be conclusively determined, but different species composition or stresses are probably responsible for the different spectral response. Solar elevation, azimuth, and background reflectance effects probably have a minor role in explaining the year to year differences.

2) Indirect Approach

Since the direct approach to leaf area index estimation did not perform well between years,an indirect approach to LAI estimation was used in which LAI was estimated indirectly with the use of canopy interception of photosynthetically active radiation (IPAR). This method originally used by Asrar et al. (1984a) to estimate LAI of wheat. Solar angle and canopy geometry were taken into account. From quantities measured in the field the interception of PAR was calculated as,

$$IPAR = (PAR_i - PAR_r - PAR_t)/PAR_i \qquad [7]$$

where PAR_i, PAR_r, and PAR_t are incoming, reflected, and transmitted PAR, respectively. The amount of PAR reflected from the soil surface was found to be small and was assumed to be zero. Monsi and Saeki (1952) defined PAR interception as,

$$IPAR = 1-e^{(-K'.LAI)} \quad [8]$$

where K' is the leaf angle shape coefficient. This equation can be changed to estimate LAI,

$$LAI = -\ln(1-IPAR)/K'. \quad [9]$$

In homogeneous canopies with spherical leaf angle distribution, K' is defined as,

$$K' = 0.5/\cos n \quad [10]$$

where n is the solar zenith angle. Thus, if the PAR interception and solar zenith angle are known an estimate of LAI can be calculated (Asrar et al., 1984a). Interception has been related to reflectance indices in previous studies on crops (Steven et. al., 1983, Hatfield et. al., 1984). Linear relationships between measured PAR interception (Eq. 7) and NIR/RED (Fig. 6), GN (Figure A6), and ND (Figure A7) were developed (Table 4) from data collected on the Konza prairie during 1984 and 1985. Reflectance data from 1983 were then used to calculate estimates of interception from these relationships. The daily means of estimated interception and calculated K' (Eq. 10) were used to estimate LAI (Eq. 9) for the 1983 season. Estimated LAI values were compared with measured LAI from 1983.

For both Barnes and Exotech data the equation using greenness (Figure A8) to estimate the interception overestimated leaf area index and was significantly different than a 1:1 relationship (Table 5). When normalized difference was used to

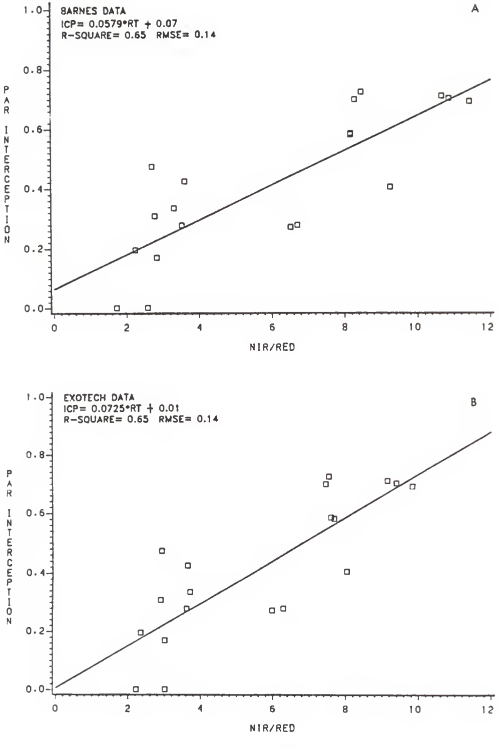


Figure 6. Relationship between PAR interception and NIR/RED developed from 1983 and 1984 data from Barnes (A) and Exotech (B) radiometers.

Table 4. Regression statistics for PAR interception estimated from GN, ND, and NIR/RED from Barnes and Exotech data collected in 1984 and 1985.

RADIOMETER	INDEX	SLOPE	INTER-CEPT	R^2	RMSE
Barnes	NIR/RED	0.0579	0.0654	0.6509	0.1396
	GN	2.1503	-0.0885	0.7876	0.1089
	ND	1.0523	-0.2538	0.6410	0.1416
Exotech	NIR/RED	0.0725	0.0066	0.6487	0.1401
	GN	3.1319	-0.0577	0.7381	0.1209
	ND	1.2547	-0.3800	0.6298	0.1438

Table 5. Regression statistics for measured versus estimated (indirectly) LAI for models where GN, ND, and NIR/RED from Barnes and Exotech data.

RADIOMETER	INDEX	F_{calc}	P VALUE
Exotech	GN	15.39	0.0000
Barnes	GN	25.34	0.0000
Exotech	ND	2.75	0.0131
Barnes	ND	2.63	0.0167
Exotech	NIR/RED	1.62	0.1393
Barnes	NIR/RED	2.02	0.0589

estimate interception, the relationship between measured and estimated LAI (Figure A9) was improved for both Barnes and Exotech data. However, both were significantly different than a 1:1 relationship ($p=0.017$ for Barnes and $p=0.013$ for Exotech), but the p values are substantially greater than those for the greenness equation. When NIR/RED was used (Fig. 7) the relationship was improved and was not significantly different than a 1:1 line. The temporal trend of this model is shown in Figure 8.

We conclude that the best results for indirect estimation of LAI were obtained when NIR/RED was used in the model to estimate interception. In this case the estimated LAI values were not different from the measured LAI values. Good agreements (based on R^2 values) were found between measured LAI and that estimated based on ND and GN, but these relationships were different than 1:1 lines.

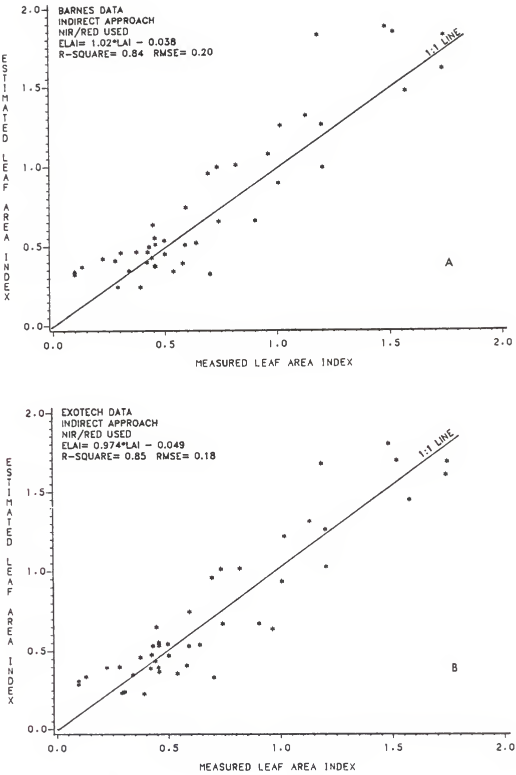
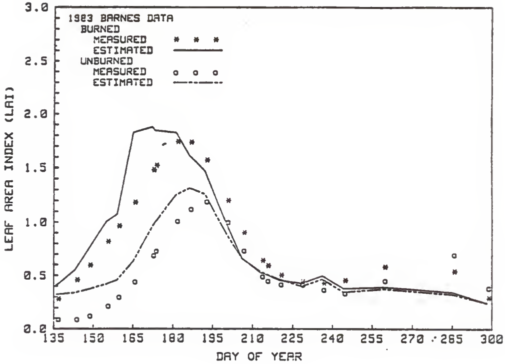


Figure 7. Leaf area index estimated indirectly using NIR/RED reflectance data to estimate PAR interception (Barnes (A) and Exotech (B) radiometer data).



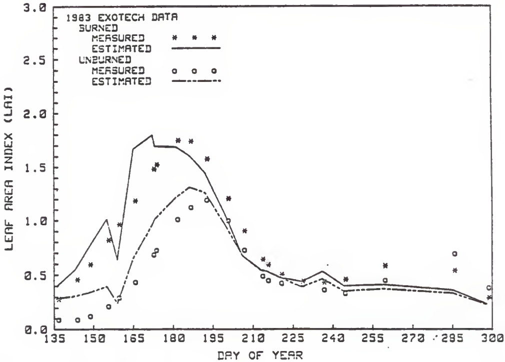


Figure 8. Seasonal trend in measured and indirectly estimated phytomass for 1983 data.

B. PHYTOMASS ESTIMATION
1) DIRECT APPROACH---REGRESSIONS

Direct estimates of dry weight of above-ground green phytomass (GP) may be preferred to LAI for some resource inventory and management activities. Estimates of green phytomass are also needed for forage availability, primary productivity, and related studies.

The different treatments and sites studied provide a range of species compositions, as discussed earlier, as well as phytomass dry weights through each season. Because the reflectance indices respond primarily to green plant material, only data from the early portion of the season (before day of year 190, July 9) were used because the relationship between a particular index and green phytomass changes as the photopigments degrade and cell structure changes during senescence, thus altering the reflectance characteristics of a given phytomass value. The three reflectance indices (GN, ND, and NIR/RED) were regressed with green phytomass for each treatment-year combination. Regressions of NIR/RED with green phytomass (Fig. 9, Table 6) were calculated for the 1983 and 1984 turned and unburned treatments. For a given green phytomass value, the unburned treatment of 1984 (U84) had the lowest NIR/RED values based on the data from both radiometers. The next highest were obtained on the unburned treatment of 1983 (U83). The NIR/RED response was greater for the burned treatments for both years. The low NIR/RED values in the unburned treatments indicate the reflectance characteristics of the green phytomass are different, possibly due to the litter background. Statistical tests (Table 7)

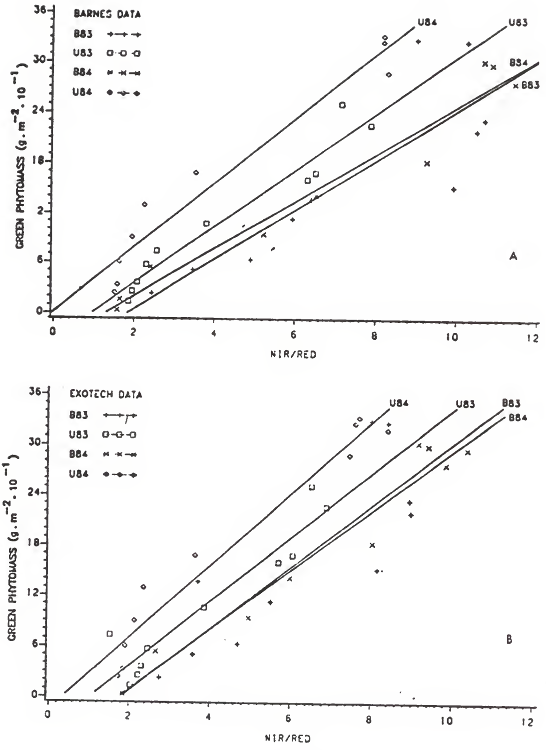


Figure 9. Relationship between green phytomass and NIR/RED for the different treatment-year combinations for Barnes(A) and Exotech (B) data.

Table 6. Linear regression statistics for estimation of green phytomass from greenness, normalized difference, and NIR/RED for the burned and unburned treatments for 1983 (B83 and U83) and 1984 (B84 and U84).

BARNES DATA

COMPARISON	TREATMENT	SLOPE	INTERCEPT	R-SQUARE	RMSE
PHYTO VS. GN	B83	89.12	-7.559	0.8356	4.44
	U83	92.38	-10.58	0.9119	2.53
	B84	85.73	-3.504	0.9204	3.38
	U84	128.3	-8.055	0.9731	2.05
PHYTO VS. ND	B83	63.22	-28.66	0.6071	6.86
	U83	42.15	-11.28	0.9163	2.46
	B84	42.19	-10.87	0.7907	5.48
	U84	48.59	-6.866	0.9746	1.98
PHYTO VS. NIR/RED	B83	2.988	-5.451	0.6843	6.15
	U83	3.405	-3.224	0.9391	2.11
	B84	2.858	-3.669	0.9508	2.66
	U84	3.881	0.159	0.9403	3.04

EXOTECH DATA

COMPARISON	TREATMENT	SLOPE	INTERCEPT	R-SQUARE	RMSE
PHYTO VS. GN	B83	138.0	-8.497	0.8337	4.46
	U83	110.9	-4.126	0.8431	3.38
	B84	139.2	-5.651	0.9138	3.41
	U84	165.5	-2.250	0.9731	2.09
PHYTO VS. ND	B83	71.37	-32.41	0.5971	6.95
	U83	38.07	-8.601	0.7334	4.41
	B84	56.36	-19.79	0.8068	5.09
	U84	4.295	-1.474	0.9482	2.89
PHYTO VS. NIR/RED	B83	3.688	-6.584	0.6461	6.51
	U83	3.843	-3.954	0.8830	2.92
	B84	3.559	-6.235	0.9455	2.71
	U84	4.295	-1.474	0.9482	2.89

Table 7. Comparison of regression models of green phytomass versus each reflectance index for the different treatment-year combinations.

GREEN PHYTOMASS

REGRESSION	COMPARISON	BARNES DATA Fcalc	BARNES DATA p value	EXOTECH DATA Fcalc	EXOTECH DATA p value
PHYTO VS. NIR/RED	B83 VS. U83	1.91	0.1805	0.87	0.4381
	B84 VS. U84	22.81	0.0000	21.50	0.0000
	B83 VS. B84	0.09	0.9107	0.03	0.9686
	U83 VS. U84	10.79	0.0013	5.94	0.0118
	all trts.	5.96	0.0003	4.33	0.0028
PHYTO VS. GN	B83 VS. U83	0.93	0.4166	0.55	0.5874
	B84 VS. U84	9.98	0.0020	15.54	0.0002
	B83 VS. B84	1.51	0.2545	1.39	0.2799
	U83 VS. U84	46.76	0.0000	29.80	0.0000
	all trts.	8.88	0.0000	8.78	0.0000
PHYTO VS. ND	B83 VS. U83	1.90	0.1818	1.97	0.1718
	B84 VS. U84	7.03	0.0077	9.47	0.0022
	B83 VS. B84	1.35	0.2886	0.62	0.5488
	U83 VS. U84	27.97	0.0000	11.79	0.0007
	all trts.	4.45	0.0025	4.15	0.0036

were performed to see if regression lines for the different year-treatment combinations differed signifigantly. The burned and unburned treatments for 1983 were not found to be different for the Barnes or Exotech data and had p values of 0.1805 and 0.4381, respectively. The two treatments were different in 1984, both radiometers having p values less than the standard 0.05 signifigance level. When comparing each treatment over the 2 years, the burned treatments were not different while the unburned treatments were. Similar results were found for greenness and normalized difference (Figures A10&A11, Table 7).

Since the individual regressions for B83 and U83 of green phytomass versus each reflectance index did not differ significantly they were combined to get a single least square estimate (Table 8). The resulting regression equations to calculate estimated green phytomass (EGP) were tested with data from 1984.

The equations based on greenness (Figure A12) slightly underestimated green phytomass. The regression equations (Table 9) had R^2 values of 0.88 and 0.85 for Barnes and Exotech, respectively. However, when compared to a 1:1 line the p values are less than 0.05 indicating that the regression lines were not the same. When normalized difference was used (Figure A13) to estimate GP the R^2 values dropped to 0.79 for Barnes and 0.80 for Exotech and sensitivity at high phytomass decreases, but p values show the regressions are not different from the 1:1 relationship. The near infrared to red ratio (Fig. 10) had similar R^2 values to ND and was not different than a 1:1 line for data from either radiometer. The seasonal trend in this model is shown in Figure A14.

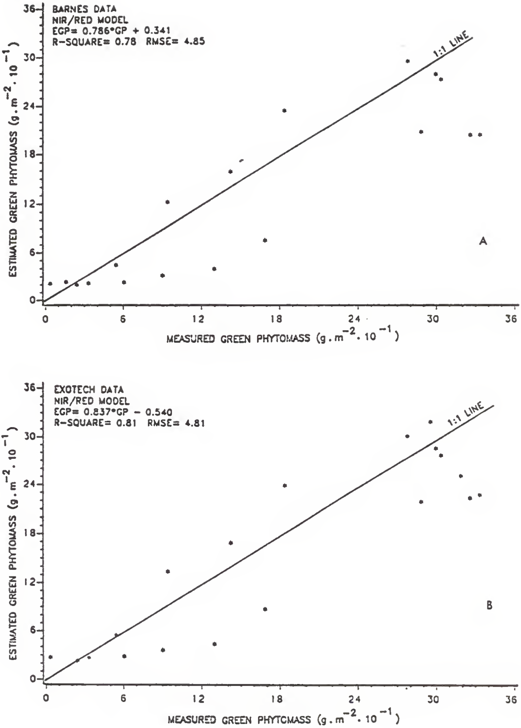


Figure 10. Green phytomass dry weight as estimated from 1984 reflectance data by a NIR/RED relationship is compared to measured values for Barnes (A) and Exotech (B) data.

Table 8. Regression statistics for green phytomass (dependent variable) versus each reflectance index for all 1983 data.

RADIOMETER	INDEX	SLOPE	INTERCEPT	R-SQUARE	RMSE
BARNES	GN	92.31	-9.500	0.8687	3.60
	ND	44.52	-13.92	0.7033	5.41
	NIR/RED	2.776	-2.227	0.7639	4.83
EXOTECH	GN	124.7	-6.060	0.8490	3.86
	ND	44.09	-12.72	0.6198	6.12
	NIR/RED	3.430	-3.663	0.7455	5.01

Table 9. Regression statistics for green phytomass estimated by each reflectance index (dependent variable) versus measured green phytomass for 1984 data.

RADIO-METER	INDEX	SLOPE	INTER-CEPT	R-SQUARE	RMSE	P-VALUE
BARNES	GN	0.8404	-3.882	0.8823	3.63	0.0017
	ND	0.8673	-3.215	0.7866	5.31	0.0922
	NIR/RED	0.7859	0.3407	0.7839	4.85	0.1795
EXOTECH	GN	0.7816	-2.047	0.8512	3.86	0.0037
	ND	0.7232	0.5402	0.8029	4.23	0.3340
	NIR/RED	0.8374	0.5400	0.8089	4.81	0.3572

We conclude that estimates of green phytomass in the prairie for the growth portion of the season can be obtained from reflectance indices. We found NIR/RED and ND estimates of green phytomass from regression equations tested on an independent data set not to be signifigantly different than 1:1 relationships and had R^2 values ranging from 0.78 to 0.81. GP estimated based on greenness index versus measured GP regression lines were found to be different than 1:1 relationships for both Barnes and Exotech data, but had higher R^2 values than either NIR/RED or ND.

2) INDIRECT APPROACH

Biscoe et.al. (1975) found net photosynthesis of a barley (_Hordeum vulgare_ L.) canopy depended on the photosynthetic response of leaves to light, the vertical distribution of those leaves, and the vertical distribution of light in the canopy. Net photosynthesis and the accumulation of phytomass is thus dependent on the amount of intercepted PAR during growth, and total phytomass accumulation could be estimated from cumulative values of PAR interception. The photochemical efficiency (ratio of chemical energy stored in dry matter to absorbed PAR) could be estimated by the slope of the line describing the relationship of total phytomass (dependent variable) to cumulative PAR interception (independent variable). Hodges and Kanemasu (1977), Monteith (1977), Asrar et.al. (1984b), and others have described the photochemical efficiency for different crops and applications. In this analysis an indirect procedure was used to estimate the dry weight of phytomass accumulated during a given growing season. The photochemical efficiency of the vegetation at the Konza prairie is approximated from data collected in 1984

and applied to 1983 data.

The relationship of PAR interception and NIR/RED (Table 4) was used to predict IPAR for the 1984 season. The absolute amount of daily PAR intercepted (APAR) by the canopy was estimated from,

$$APAR = I_0 * K_f * EPAR \qquad [11]$$

where I_0 is the daily solar radiation (MJ m^{-2}); K_f is the fraction of the total incoming radiation in the PAR region (assumed to be 0.5); and EPAR is the fraction of intercepted PAR as estimated from NIR/RED.

Cumulative interception (CUMICP) was obtained by integrating the estimate of absolute interception (APAR) over the 1984 season. An exponential model was developed (Fig. 11) to estimate green phytomass (EGP).

$$EGP_{barnes} = 405.1(1 - e^{-0.008011*CUMICP}),\ R^2 = 0.993 \qquad [12]$$

$$EGP_{exotech} = 394.1(1 - e^{-0.008725*CUMICP}),\ R^2 = 0.994 \qquad [13]$$

The derived relationships indicate that photochemical efficiency is variable, apparently depending on the stage of plant development. The photochemical efficiency can be estimated by differentiating these equations to obtain the instantaneous slope. For the Barnes relationship the slope ranges from 3.25 g/MJ at CUMICP=0 to 0.44 g/MJ at CUMICP=250. Similarly for Exotech these values were 3.44 and 0.39 g/MJ. Average values for this time period are 1.30 and 1.38 for Barnes and Exotech, respectively. Monteith (1977) compared four crops and found the

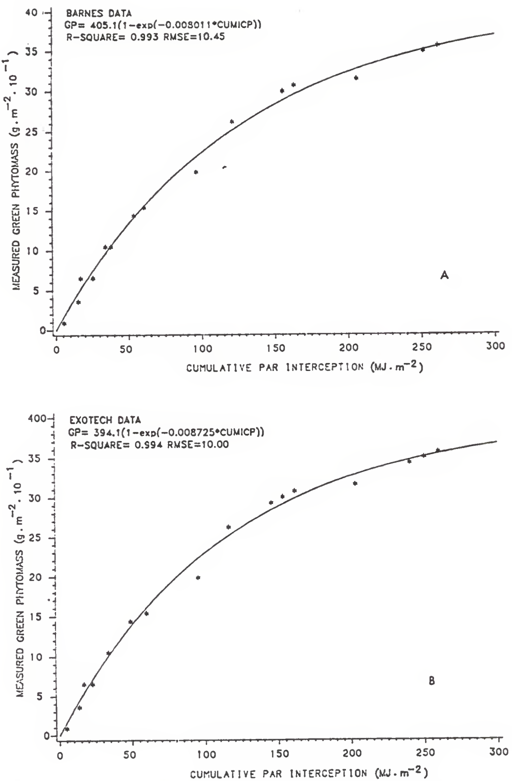
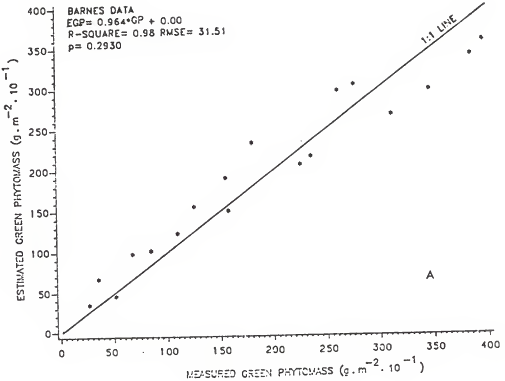


Figure 11. Exponential relationship for cumulative PAR interception versus accumulated green above-ground phytomass from 1984 Barnes (A) and Exotech (B) data.

slope to be about 1.4 g/MJ. Equations [12] and [13] were tested on the 1983 data set. The NIR/RED was calculated from Barnes and Exotech reflectance data and averaged for the burned and unburned treatment on each day of data collection. Estimates of interception for each day and treatment were calculated from NIR/RED (Table 4) and used with daily solar radiation (Eq. 11) to calculate the absolute PAR intercepted. These values were integrated over time resulting in cumulative interception. Estimated green phytomass was calculated (Eqs. 12&13) from these values and regressed (zero intercept model used) with the 1983 accumulation of measured total phytomass (Fig. 12). Comparisons with a 1:1 line indicated this indirect method of estimating green phytomass for burned and unburned treatments performed well as illustrated by the p values of 0.2930 and 0.1495 (Fig. 12). The Barnes and Exotech data provide similar results. Figure 13 shows the data plotted through the season. From this graph it appears that modelled estimates for the burned treatment were consistent with measured values, but modelled estimates of phytomass for the unburned treatment were high early and low late in the season.

In summary, dry weight of above-ground green phytomass on the Konza prairie was estimated by linear regression with either NIR/RED or normalized difference using data from both radiometers. Dry weight of accumulated above-ground green phytomass was successfully predicted for the growth portion of the season by estimating and integrating canopy interception from NIR/RED, combined with incoming radiation, and photochemical efficiency. It appears the model performed better on the burned than the unburned treatment.



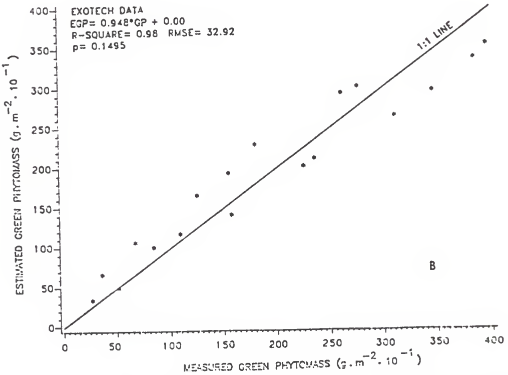


Figure 12. Estimated versus measured dry weight of above-ground phytomass using 1983 Barnes (A) and Exotech (B) data.

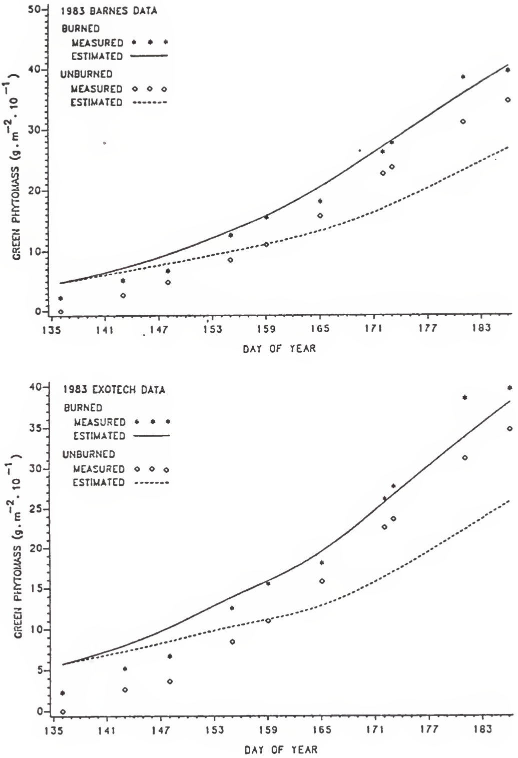


Figure 13. Seasonal trend in measured and estimated phytomass 1983 Barnes and Exotech data.

CONCLUSIONS

LAI and phytomass of the Konza were successfully estimated directly from the spectral reflectance and indirectly by first estimating PAR interception. The direct relationships between spectral reflectance and LAI or phytomass were different for the 2 years of this study. The indirect approach for estimating both LAI and phytomass overcame the site dependency and provided better estimates of these parameters. Since this approach is based on physical properties of canopy structure (for LAI) and energy absorption (for phytomass) the application should extend to different sites, years, and canopy types.

APPENDIX

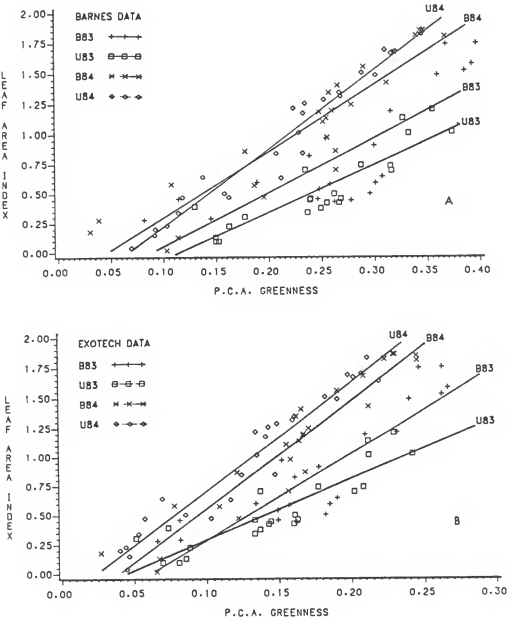


Figure A1. Relationship between leaf area index and greenness for different treatment-year combinations for Barnes (A) and Exotech (B) data.

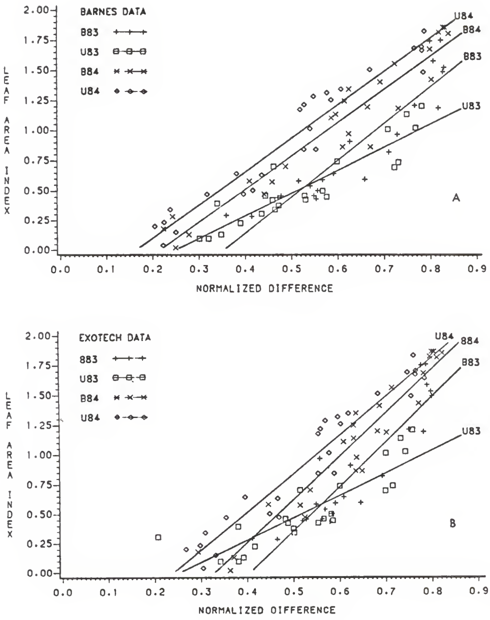


Figure A2. Relationship between leaf area index and normalized difference for different treatment-year combinations for Barnes (A) and Exotech (B) data.

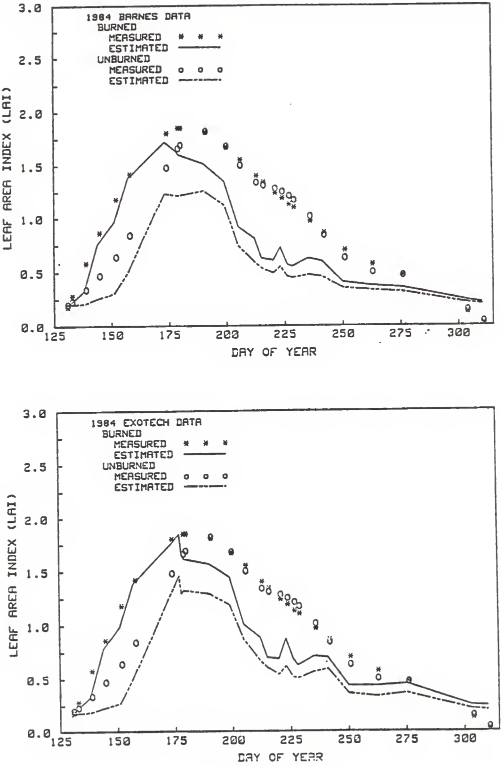
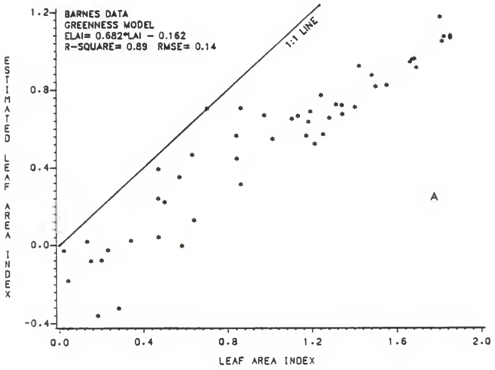


Figure A3. Seasonal trend in regression model predictions of LAI for 1984 data.



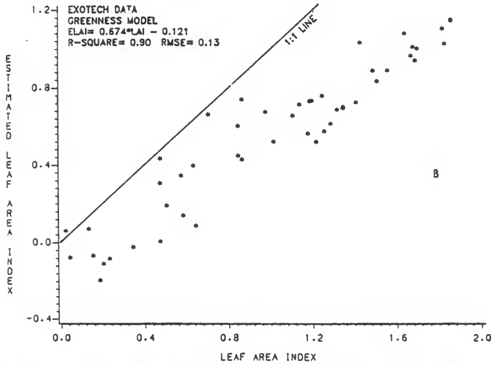
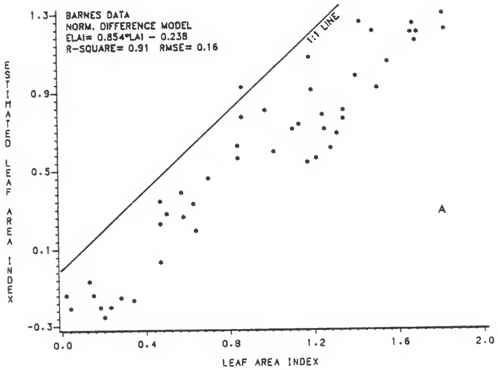


Figure A4. Leaf area index estimated from 1984 Barnes (A) and Exotech (B) data is regressed with 1984 measured LAI. Leaf area index was estimated from the greenness model developed from 1983 data.



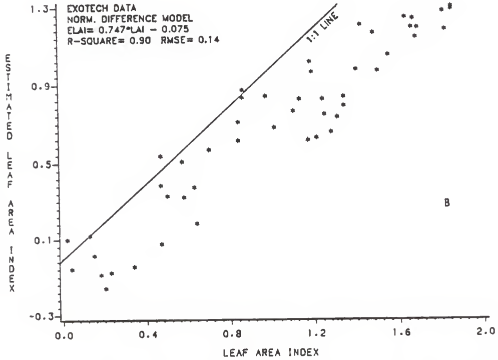


Figure A5. Leaf area index estimated from 1984 Barnes (A) and Exotech (B) data is regressed with 1984 measured LAI. Leaf area index was estimated from the normalized difference model developed from 1983 data.

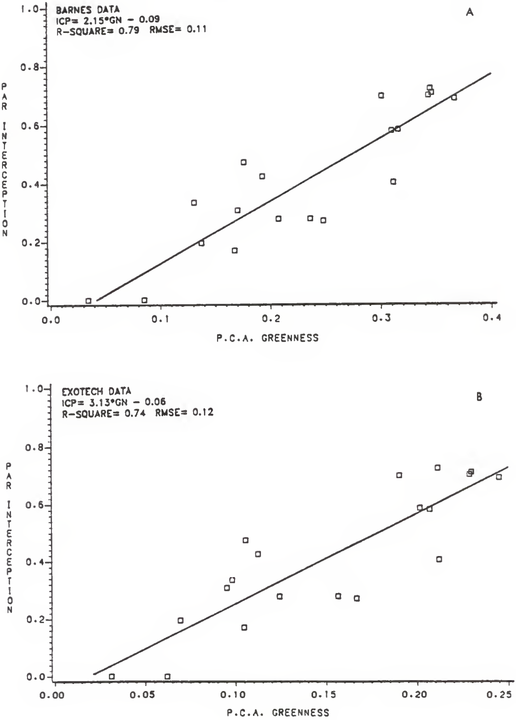
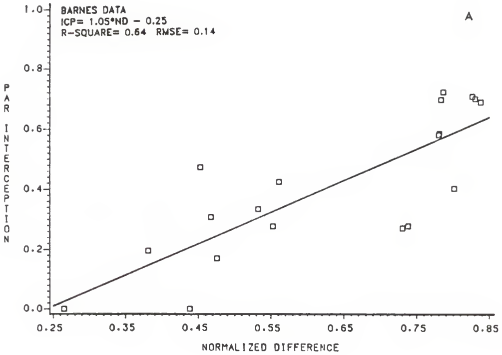


Figure A6. Relationship between PAR interception and greenness developed from 1983 and 1984 data from Barnes (A) and Exotech (B) radiometers.



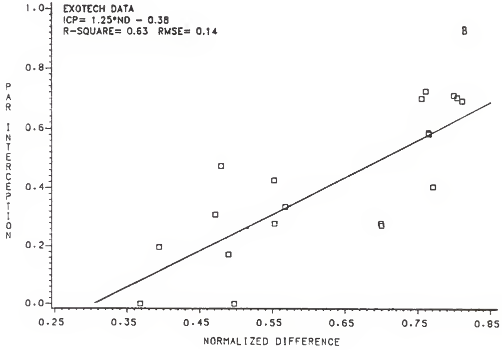
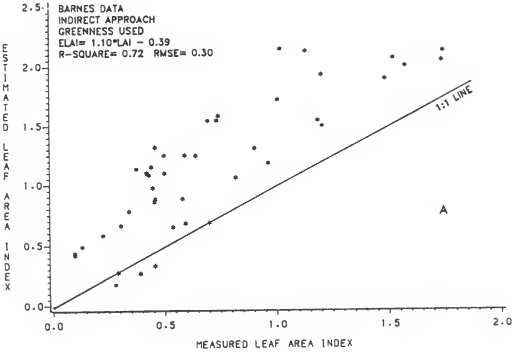


Figure A7. Relationship between PAR interception and normalized difference developed from 1983 and 1984 data from Barnes (A) and Exotech (B) radiometers.



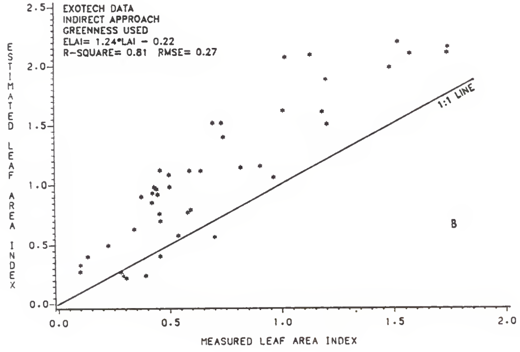
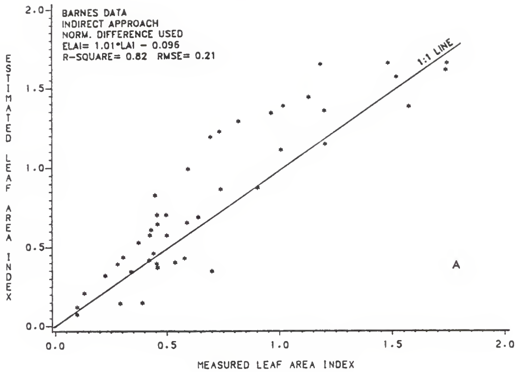


Figure A8. Leaf area index estimated indirectly from reflectance data by first estimating PAR interception from greenness for both Barnes (A) and Exotech (B) radiometer data.



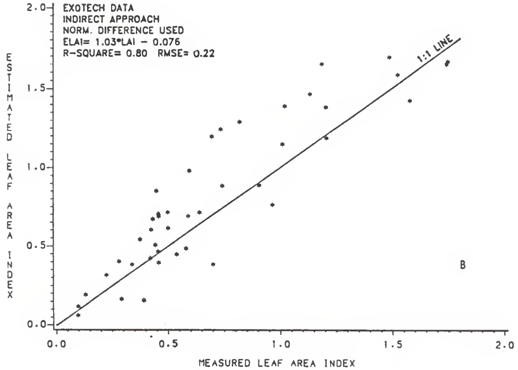


Figure A9. Leaf area index estimated indirectly from reflectance data by first estimating PAR interception from normalized difference for both Barnes (A) and Exotech (B) radiometer data.

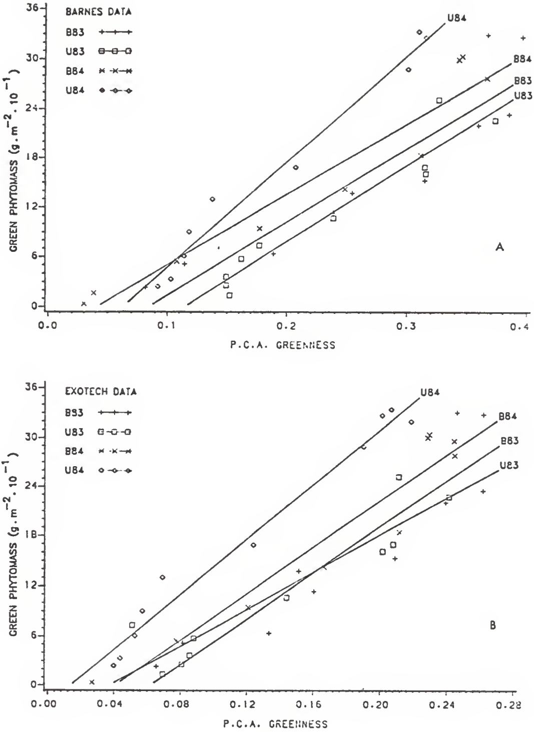
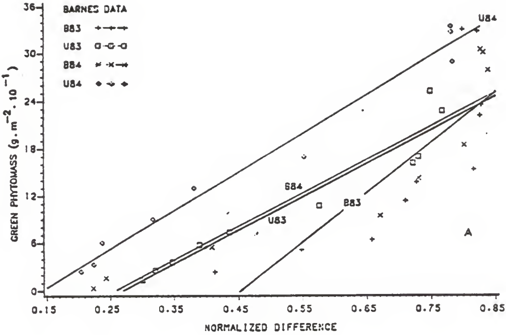


Figure A10. Relationship between green phytomass and greenness for the different treatment-year combinations for Barnes(A) and Exotech (B) data.



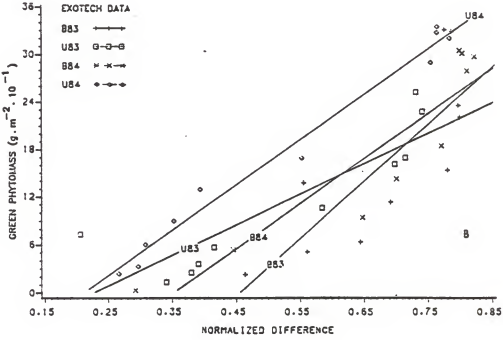


Figure A11. Relationship between green phytomass and normalized difference for the different treatment-year combinations for Barnes(A) and Exotech (B) data.

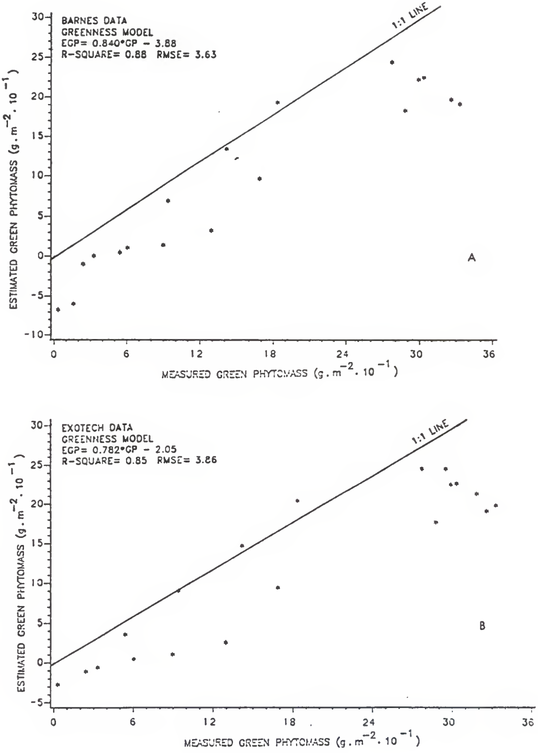


Figure A12. Green phytomass dry weight as estimated from 1984 reflectance data by a greenness relationship is compared to measured values for Barnes (A) and Exotech (B) data.

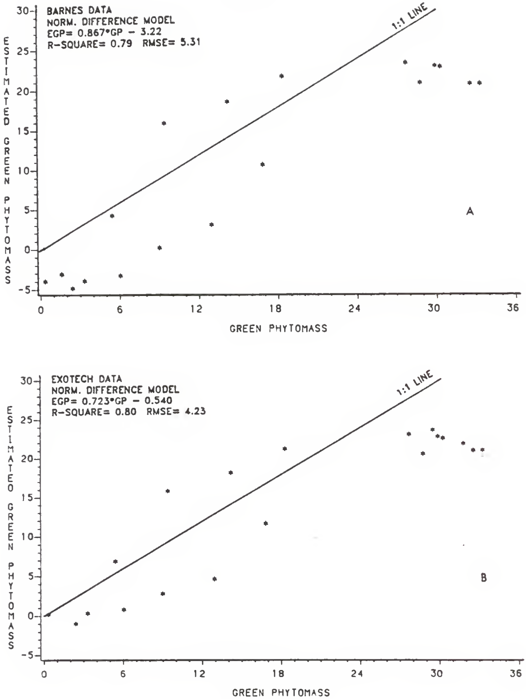
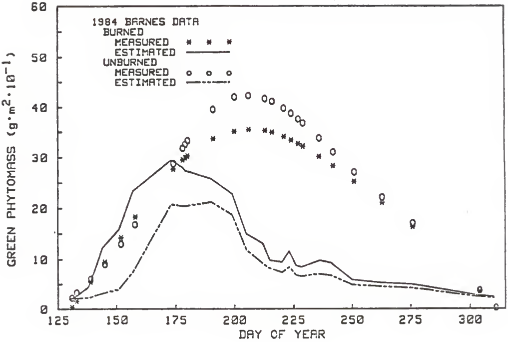


Figure A13. Green phytomass dry weight as estimated from 1984 reflectance data by a normalized difference relationship is compared to measured values for Barnes (A) and Exotech (B) data.



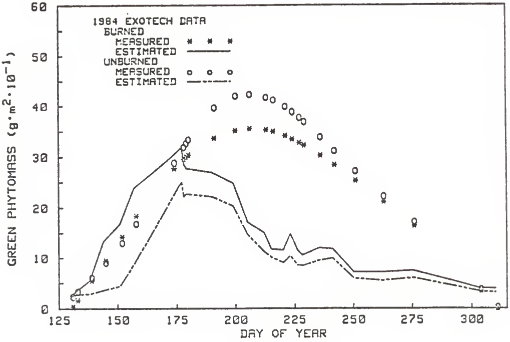


Figure A14. Seasonal trend in regression model predictions of green phytomass for 1984 data.

Table A1

August 23, 1983

VEGETATION COMPOSITION OF ET LAB SPECTRAL REFLECTANCE STUDY AREAS ON KONZA PRAIRIE RESEARCH NATURAL AREA

Location: Kansas, Riley County, southeastern part of sec. 19, T11S, R8E. Konza Prairie Research Natural Area, grid R27. Flat ridge.

Soil: Dwight-Irwin complex, 1 to 4 percent slope. The Dwight silt loam is a claypan range site, the Irwin silty clay loam a clay upland range site.

Date: Field sampling was done August 15, 1983 by Lloyd C. Hulbert.

Method: Canopy coverage was recorded for each species in 20 circular plots of 10 m^2 area in each site. The burned site is in area 1D, burned each spring since 1978 in late April. The area was burned April 20, 1983. The unburned area across the fireguard (area N1B) has not been burned since the area was added to Konza Prairie in 1977, and for some unknown number of years before that.

The method follows that of Daubenmire, R. 1959. A canopy-coverage method of vegetational analysis. Northwest Science 33(1):43-64. The only modification was by adding another category, 0 to 1 percent. The categories used were:

Area	Category number	Midpoint
up to 1%	1	0.5%
1 to 5	2	3
5 to 25	3	15
25 to 50	4	37.5
50 to 75	5	62.5
75 to 95	6	85
95 to 100	7	97.5

Canopy is defined as the area within lines connecting extremities of the plant canopy.

Legend: First figure is average canopy coverage in the 20 plots.
Second figure is frequency, the per cent of the plots in which the species occurred.
Example: 0.4/30 Canopy of the species occupied 0.4% of the area and the species occurred in 6 of the 20 plots (30%).

Interpretation: Differences are due to treatment, soil variability and chance. Small differences are likely to be due to sampling error or chance. Occurrence of a species in one or two plots in one treatment but not the other could be due to chanceof being included in the sampling. Analysis of the individual plot data by t-tests could aid interpretation, but greater reliability could be obtained by comparison with results of other sampling in a variety of areas. If such information is needed, let me know.

Some of the results agree with previous findings. For example, spring burning is detrimental to cool-season species, as evidenced by the differences for Poa pratensis, Bromus japonicus, and Symphoricarpos orbiculatus.

Species preceded by an asterisk are introduced from Eurasia.

Nomenclature: follows the Flora of the Great Plains (in preparation).

Lloyd C. Hulbert
Biology

	Unburned area	Burned area
Tall, perennial warm-season grasses		
Andropogon gerardii, big bluestem	96.25/100	92.625/100
Sorghastrum nutans, indiangrass	22.25/100	61.875/100
Panicum virgatum, switchgrass	2.75/40	10.025/40
Medium and short perennial warm-season grasses		
Andropogon scoparius, little bluestem	31.0/100	60.625/100
Sporobolus asper var. asper, tall dropseed	10.8/70	4.925/55
Bouteloua curtipendula, side-oats grama	0	0.525/80
Eragrostis spectabilis, purple lovegrass	0	0.075/15
Sporobolus heterolepis, prairie dropseed	0.15/5	0
Muhlenbergia cuspidata, plains muhly	0.025/5	0
Bouteloua gracilis, blue grama	0	0.6/45
Bouteloua hirsuta, hairy grama	0	0.25/25
Buchloe dactyloides, buffalograss	0	0.025/5
Cool season perennial grasses		
Poa pratensis, Kentucky bluegrass	47.625/100	0
Dicanthelium oligosanthes var. scribnerianum (Panicum scribnerianum), scribner panicum	2.95/100	0.575/90
*Bromus inermis subsp. inermis, smooth brome	0.75/5	0
Koeleria pyramidata, prairie junegrass	0.025/5	0.375/75
Annual grasses		
*Bromus japonicus, Japanese brome	0.4/30	0
Grass-like plants (Cyperaceae)		
Carex spp., sedges	2.45/95	1.675/90
Cyperus lupulinus (C. filiculmis), fern flatsedge	0	0.1/20
Woody plants		
Amorpha canescens, leadplant	0	0.075/15
Symphoricarpos orbiculatus, buckbrush	0.375/25	0
Perennial forbs		
Ambrosia psilostachya, western ragweed	7.55/95	0.75/100
Artemisia ludoviciana, Louisiana sagewort	4.85/90	0
Asclepias viridis, green antelopehorn	1.45/65	0.95/65
Baptisia bracteata var. glabrescens, plains wildindigo	1.425/40	0.575/40
Achillea millefolium subsp. lanulosa, western yarrow	1.25/75	0.025/5
Vernonia baldwinii var. interior, inland ironweed	0.575/65	0.45/40
Salvia pitcheri, pitcher sage	0.5/25	0.975/45
Aster ericoides, heath aster	0.475/45	2.375/85
Ruellia humilis, fringeleaf ruellia	0.325/65	0.325/65
Cirsium undulatum, wavyleaf thistle	0.25/25	0.075/15
Dalea purpurea var. purpurea, purple prairieclover	0.2/40	0.15/30
Astragalus crassicarpus var. crassicarpus, groundplum milkvetch	0.2/15	0.5/25
Asclepias verticillata, whorled milkweed	0.175/35	0.025/5
Desmodium illinoense, Illinois tickclover	0.175/10	0.05/10
Physalis pumila, prairie groundcherry	0.175/10	0.025/5
Asclepias stenophylla, narrowleaf milkweed	0.1/20	0.175/35
Dalea candida, white prairieclover	0.05/10	0.025/5
Callirhoe involucrata, purple poppymallow	0.05/10	0
Kuhnia eupatorioides var. corymbulosa, falseboneset	0.025/5	0.325/40
Lespedeza capitata, roundhead lespedeza	0.025/5	0
Physalis virginiana, Virginia groundcherry	0.025/5	0

	Unburned area	Burned area
Perennial forbs, continued		
Solidago missouriensis var. fasciculata, Missouri goldenrod	0.025/5	0.175/35
Aster oblongifolius, aromatic aster	0.025/5	0
Ratibida columnifera, upright prairieconeflower	0	0.2/40
Asclepias viridiflora, green milkweed	0	0.05/10
Aster sericeus, silky aster	0	0.05/10
Sisyrinchium campestre, prairie blue-eyedgrass	0	0.025/5
Apocynum cannabinum, hemp dogbane	0	0.025/5
Physalis heterophylla, clammy groundcherry	0	0.025/5
Annual and biennial forbs		
Lactuca sp., wild lettuce	0.025/5	0
Euphorbia marginata, snow-on-the-mountain	0.025/5	0
Linum sulcatum, grooved flax	0	0.4/80
Tragopogon dubius, western salsify	0	0.025/5
Total number of species	39	41

A2. Canopy coverage/frequency of plant species in spectral reflectance study sites, Konza Prairie Research Natural Area, September 5, 1984.

	Unburned SW of 10C upper slope	Burned SE of 1C upper slope	Burned S side 1C lower slope
TALL WARM-SEASON PERENNIAL GRASSES			
Andropogon gerardii, big bluestem	80/100	86/100	98/100
Sorghastrum nutans, indiangrass	40/100	69/100	48/100
Panicum virgatum, switchgrass	9/40	0.3/10	90/100
MEDIUM HEIGHT, WARM-SEASON PERENNIAL GRASSES			
Andropogon scoparius, little bluestem	13/90	50/100	19/90
Bouteloua curtipendula, side-oats grama	3/90	24/100	1.3/60
Sporobolus asper var. asper, tall dropseed	52/100		6/100
Sporobolus heterolepis, prairie dropseed	0.3/10		
Total of all perennial C4 grasses	199/530	230/410	262/550
COOL SEASON PERENNIAL GRASSES AND SEDGES			
Poa pratensis, Kentucky bluegrass	11/100		
Koeleria pyramidata, prairie junegrass	0.2/50	0.1/20	
Dicantelius oligosanthesea var. scribnerianus, scribner's panicum	1.4/90	0.3/60	0.2/30
Elymus canadensis, Canada wildrye	1.5/10		
Carex spp.	6/80	0.3/10	
Total C3 grasses and grasslike	20/330	0.7/90	0.2/30
ANNUAL GRASSES			
Bromus japonicus, Japanese brome	1.5/10		
PERENNIAL FORBS			
Achillea millefolium var. lanulosa, western yarrow	0.6/80		
Ambrosia psilostachya, western ragweed	25/100	0.5/50	3/80
Artemisia ludoviciana, Louisiana sagewort	1.5/10	0.05/10	
Asclepias stenophylla, narrow-leaved milkweed		0.15/30	
Asclepias verticillata, whorled milkweed	0.3/60	0.05/10	0.2/40
Asclepias viridiflora, green milkweed		0.1/20	
Aster ericoides, heath aster	45/100	0.2/30	0.5/50
Aster oblongifolius, aromatic aster	0.05/10		
Aster sericeus, silky aster	1.9/40		
Baptisia bracteata, plains wildindigo	0.6/30	0.7/40	
Dalea candida, white prairieclover	0.4/20		
Dalea purpurea, purple prairieclover	0.05/10		0.05/10
Desmodium illinoense, Illinois tickclover			0.3/10
Kuhnia eupatorioides var. corymbulosa, boneset		2/60	0.2/30
Lespedeza capitata, roundhead lespedeza			0.2/30
Lespedeza violacea, violet lespedeza			0.05/10
Physalis pumila, prairie groundcherry	0.1/20		
Psoralea tenuiflora var. floribunda, manyflower scurfpea	0.3/10		
Ruellia humilis, fringeleaf ruellia	0.4/70	0.2/40	0.4/70

continued on next page

Salvia pitcheri, pitcher's sage	1.5/30		
Solanum carolinense, horsenettle	0.05/10		
Solidago canadensis var. *scabra*, Canada goldenrod	0.05/10		0.05/10
Solidago missouriensis var. *rigidus*, Missouri goldenrod	0.6/60	0.3/60	0.1/20
Vernonia baldwinii var. *interior*, inland ironweed	3/100	1.2/90	0.8/100
Total, perennial forbs	80/770	6/440	6/460
WOODY PLANTS			
Amorpha canescens, leadplant	10/80	19/90	
ANNUAL AND BIENNIAL FORBS			
Lactuca ludoviciana, Louisiana lettuce	0.1/20		
Linum sulcatum, grooved flax	0.1/20		
Triodania perfoliata, claspinglookingglass	0.05/10		
Total, all plants	312/1770	255/1030	268/1040

Averages of data from 10 plots, each 10 square meters.
Scientific names according to Great Plains Flora.
Ratings by Lloyd C. Hulbert, following method of R. Daubenmire. 1959. A canopy coverage method of vegetation analysis. Northwest Science 33:43-66. The method was modified by adding an additional category of 0 to 1%.

Test A1.

To test if measured and estimated values of a parameter are different an F value was calculated as,

$$F = \frac{(obs_{est} - obs_{meas})^2/n}{\text{model SS}/df_{model}}$$

where obs_{est} is the estimated value and obs_{meas} is the measured value of an observation, n is the number of observations. Model SS is the sum of squares for the original model from which estimates were made and df_{model} are its degrees of freedom. For convenience p values were calculated to give an estimate of the signifigance level of a comparison. This test was developed with the help of Dr. Dallas Johnson (Statistics Dept.). We expect our calculated F follows the true F distribution but is has not been tested; however, this test does measure the relative signifigance of these comparisons in either case.

REFERENCES

Aase, J.K. 1978. Relationship between leaf area and dry matter in winter wheat. Agron. J. 70:563-565.

Asrar, G., M. Fuchs, E.T. Kanemasu, and J.L. Hatfield. 1984a. Estimating absorbed photosynthetic radiation and leaf area index from spectral reflectance in wheat. Agron. J. 76:300-306.

Asrar, G., L.E. Hipps, and E.T. Kanemasu. 1984b. Assessing solar energy and water use efficiencies in winter wheat: a case study. Agricultural and Forest Meteorology. 31:47-58.

Asrar, G., E.T. Kanemasu, and M. Yoshida. 1985a. Estimates of leaf area index from spectral reflectance of wheat under different cultural practices and solar angle. Remote Sens. of Envir. 17:1-11.

Asrar, G., E.T. Kanemasu, G.P. Miller, and R.L. Weiser. 1985b. Light interception and leaf area estimates from measurements of grass canopy reflectance. IEEE (in press).

Asrar, G., E.T. Kanemasu, R.D. Jackson, and P.J. Pinter, Jr. 1985c. Estimation of total above-ground phytomass production using remotely sensed data. Remote Sens. of Envir. 17:211-220.

Asrar, G., E.T. Kanemasu, D.E. Johnson, R.L. Weiser, and J.M. Killeen. 1985d. Distinguishing among surface cover types from measurements of multispectral reflectance in a tallgrass prairie. (in press).

Bidwell, O.W. and C.W. McBee. 1973. Soils of Kansas (map). Kansas Agric. Exp. Sta., Dept. of Agronomy, Contrib. no. 1359.

Biscoe, P.V., J.N. Gallagher, E.J. Littleton, J.L. Monteith, and R.K. Scott. 1975. Barley and its environment, IV. Sources of assimilate for the grain. J. Appl. Ecol. 12:295-318.

Boutton, Thomas W. and Larry L. Tieszen. 1983. Estimation of plant biomass by spectral reflectance in an east African grassland. J. of Range Management. 36(2):213-221.

Bowers, S.A. and R.J. Hanks. 1965. Reflection of radiant energy from soils. Soil Science. 100:130-138.

Colwell, John E. 1974. Vegetation canopy reflectance. Remote Sens. of Envir. 3:175-183.

Chance, J.E. 1981. Crop identification and leaf-area index calculations with LANDSAT multitemporal data. Int. J. Remote Sensing. 2:1-7.

Curran, Paul. 1980. Multispectral remote sensing of vegetation amount. Prog. Phys. Geogr. 4:315-341.

Daughtry, C.S.T., K.P. Gallo, and M.E. Bauer. 1983. Spectral estimates of solar radiation intercepted by corn canopies. Agron. J. 75:527-531.

Dinger, J.E. 1941. The absorption of radiant energy in plants. Iowa State Coll. J. Sci. 16:44-45.

Draper, N.R., and H. Smith. 1981. Applied regression analysis, 2nd ed. John Wiley & Sons., New York.

Fuchs, M., G. Asrar, and E.T. Kanemasu. 1984. Leaf area estimates from measurements of photosynthetically active radiation in wheat canopies. Agricultural and Forest Meteorology. 32:13-22.

Gallo, K.P, C.S.T. Daughtry, and M.E. Bauer. 1985. Spectral estimation of absorbed photosynthetically active radiation in corn canopies. Remote Sens. of Envir. 17:221-232.

Gausman, H.W. 1977. Reflectance of leaf components. Remote Sens. of Envir. 6:1-9.

Hatfield, J.L., G. Asrar and E.T. Kanemasu. 1984. Intercepted photosynthetically active radiation estimated by spectral reflectance. Remote Sens. of Envir. 14:65-75.

Hatfield, J.L., E.T. Kanemasu, G. Asrar, R.D. Jackson, P.J. Pinter, Jr., R.J. Reginato, and S.B. Idso. 1985. Leaf-area estimates from spectral measurements over various planting dates of wheat. Int. J. Remote Sensing. 6(1):167-175.

Hodges, T. and E.T. Kanemasu. 1977. Modeling daily dry matter production of winter wheat. Agron. J. 69:974-978.

Holben, B.N., C.J. Tucker, and C.J. Fan. 1980. Spectral assessment of soybean leaf area and leaf biomass. Photogramm. Eng. and Remote Sensing. 46:651-656.

Hsiao, T.C. and E. Acevedo. 1974. Plant responses to water deficits, water use efficiency and drought resistance. Agricultural Meteorology. 14:59-84.

Huete, A.R., D.F. Post, and R.D. Jackson. 1984. Soil spectral effects on 4-space vegetation discrimination. Remote Sens. of Envir. 15:155-165.

Kanemasu, E.T. 1974. Seasonal canopy reflectance patterns of wheat, sorghum, and soybean. Remote Sens. of Envir. 3:43-47.

Kimes, D.S., B.L. Markham, C.J. Tucker, and J.E. McMurtrey. 1981. Temporal relationships between spectral response and agronomic variables of a corn canopy. Remote Sens. of Envir. 11:401-411.

Knipling, Edward B. 1970. Physical and physiological basis for the reflectance of visible and near-infrared radiation from vegetation. Remote Sens. of Envir. 1:155-159.

Kollenkark, J.C., C.S.T. Daughtry, M.E. Bauer, and T.L. Housley. 1982. Effects of cultural practices on agronomic and reflectance characteristics of soybean canopies. Agron. J. 74:751-758.

Mestre, H. 1935. The absorption of radiation by leaves and algae. Cold Spring Harbor Symposia Quant. Biol. 3:191-209.

Miller, G.P., M. Fuchs, M.J. Hall, G. Asrar, E.T. Kanemasu, and D.E. Johnson. 1984. Analysis of seasonal multispectral reflectances of small grains. Rem. Sens. Environ. 14:153-167.

Monsi, M. and T. Saeki. 1953. Ueber dem lichtfaktor in den pflanzengesellschaften und seine bedeutung fuer die stoffproduktion. Jpn. J. Bot. 14:22-52.

Monteith, J.L. 1977. Climate and efficiency of crop production in Britain. Philos. Trans. R. Soc. London, Ser. B. 281:277-294.

Pollock, R.B. and E.T. Kanemasu. 1979. Estimating leaf-area index of wheat with LANDSAT data. Remote Sens. of Envir. 8:307-312.

Richardson, A.J., C.L. Wiegand, H.W. Gausman, J.A. Cuellar, and A.H. Gerbermann. 1975. Plant, soil and shadow reflectance components of row crops. Photogramm. Eng. and Remote Sens. 41:1401-1407.

Richardson, Arthur J., James H. Everitt, and Harold W. Gausman. 1983. Radiometric estimation of biomass and nitrogen content of Alicia Grass. Remote Sens. of Envir. 13:179-184.

Sinclair, T.R., Schreiber, M.M. and R.M. Hoffer. 1973. Diffuse reflectance hypothesis for the pathway of solar radiation through leaves. Agron. J. 65:276-283.

Steven, M.D. 1981. Optical remote sensing for predictions of crop yields. Proc. Soc. Photo-Optical Instrumentation Engr. 262:137-142.

Steven, M.D., Biscoe, P. V., and Jaggard, K. W., 1983. Estimation of sugarbeet productivity from reflectance in the red and infrared spectral bands. Int. J. Remote Sens. 4:325-334.

Tucker, Compton J. and Lee D. Miller. 1977. Soil spectra contributions to grass canopy spectral reflectance. Photogramm. Eng. and Remote sensing. 43(6):721-726.

Tucker, Compton J. 1977. Asymptotic nature of grass canopy spectral reflectance. Applied Optics. 16(5):1151-1156.

Tucker, Compton J., C. Vanpraet, E. Boerwinkel, and A. Gaston. 1983. Satellite remote sensing of total dry matter production in the Senegalese Sahel. 13:461-474.

Tucker, Compton J., C.L. Vanpraet, M.J. Sharman, and G. Van Ittersum. 1985. Satellite remote sensing of total herbaceous biomass production in the Senegalese Sahel: 1980-1984. Remote Sens. of Envir. 17:233-249.

Walburg, G. M.E. Bauer, C.S.T. Daughtry, and T.L. Housley. Effects of nitrogen nutrition on the growth, yield, and reflectance of corn canopies. Agron. J. 74:677-683.

Weiser, R.L., G. Asrar, G.P. Miller, and E.T. Kanemasu. 1984. Assessing biophysical characteristics of grassland from spectral measurements. Proceed. 10th International Symp. Machine Process. Remotely Sens. Data, Purdue Univ. West Lafayette, Indiana, pp. 357-361.

Wiegand, C.L., A.J. Richardson, and E.T. Kanemasu. 1979. Leaf area index estimates for wheat from LANDSAT and their implications for evapotranspiration and crop modeling. Agron. J. 71:336-341.

Wiegand, C.L. and A.J. Richardson. 1984. Leaf area, light interception, and yield estimates from spectral componints analysis. Agron. J. 76:543-548.

Willstatter, R., and A. Stoll. 1918. Untersuchungen uber die Assimilation der Kohlensaure. Springer, Berlin.

ASSESSING BIOPHYSICAL CHARACTERISTICS OF GRASSLAND FROM SPECTRAL MEASUREMENTS

by

Russell L. Weiser

B.S., Oregon State University, 1983

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Agronomy

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1985